Position Location in Mobile Systems

Project Report submitted in partial fulfilment of the requirement
for the degree of Bachelor of Technology

In

Electronics and Communication Engineering

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May 2010

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Certificate

This is to certify that the project report entitled "*Position Location in Mobile Systems*", submitted by Amardeep Singh Kohli, Ashish Acharya and Rahul Khanna in partial fulfilment for the award of degree of Bachelor of Technology in Electronics and Communication Engineering to Jaypee University of Information Technology, Waknaghat, Solan has been carried out under my supervision.

TSLamba

Date : 24/5/2010

Prof. T.S Lamba

It is certified that this work has not been submitted partially or fully to any other University or Institute for the award of this or any other degree or diploma.

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Acknowledgement

As we conclude our project with the God's grace, we have many people to thank; for all the help, guidance and support they lent us, throughout the course of our endeavour.

First and foremost, we thank Prof. T.S. Lamba, our Project Guide, who has always encouraged us to put in our best efforts and deliver a quality and professional output. His emphasis on knowledge rather than on results has helped us to achieve whatever we have in this project.

Secondly, we thank Prof. Sunil Bhooshan, Mr. Jitender Mohan, Mr. Mohd. Wajid for their patient hearing of our ideas and opening up our minds to newer horizons by pointing out our flaws, providing critical comments and suggestions to improve the quality of our work and appreciating our efforts.

Apart from these, countless events, countless people & several incidents have made a contribution to this project that is indescribable.

RKhanna

(Amardeep Singh Kohli)
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Abstract

This study addresses the wireless geolocation problem that has been an attractive subject for the last few years after Federal Communications Commission's (FCC) mandate for wireless service providers to locate emergency 911 users with a high degree of accuracy within a radius of 125 meters, 67 percent of the time by October 2001. There are a number of different geolocation technologies that have been proposed. These include Time Difference of Arrival (TDOA), Angle of Arrival (AOA), Time of Arrival (TOA), and Global Positioning System (GPS). This research focuses mainly on network based techniques, namely the TDOA which is also called hyperbolic position location technique and AOA. These techniques are studied in different environments. The main problem in time-based positioning systems is solving nonlinear hyperbolic equations derived from set of TDOA estimates. Two algorithms are implemented as a solution to this problem: A closed form solution and a Least Squares (LS) algorithm. After that a hybrid technique is evaluated having a better position estimation than the previous ones. The hybrid technique gives a superior performance over the traditional techniques discussed earlier. Finally work that can be done in the future for e.g. rural and sub-urban areas has been discussed about.

CHAPTER 1

Introduction

Communication is so important to us that the ways to communicate advance further and further every day. From copper wires to fibre optics, an age has come where wired communication doesn't meet our needs. The idea of truly mobile computing has started a new way of life, a novel way of thinking. The urge to communicate even by means of portable computers with interfaces to wireless networks has started the era of wireless communication. A recent survey found that one third of the U.S. workforce, which is 43 million workers, are mobile and spend more than 20 percent of their time working away from their primary workplace [2].

As interest in wireless communications has increased, new technologies have emerged. Geolocation has been a centre of attention for many years. Geolocation is determining the geographic location i.e., the latitude and longitude of a mobile user. This research study presents an overview of and performance comparison between wireless geolocation methods.

1.1 FCC Ruling

The primary drive for geolocation technology has been the Federal Communications Commission (FCC) mandate for wireless service providers to locate emergency 911 users with a high degree of accuracy -within a radius of 125 meters, 67 percent of the time by October 2001 [1]. Statistics show that the emergency 911 calls from cellular phones are between 20 and 60 percent of all 911 calls [4]. This ratio is growing every day as the number of cellular phone subscribers are increasing. From the standpoint of safety, wireless carriers are supposed to provide virtually the same emergency service as wired phones. In wired phones, when a 911 call is made, the nearest Public Safety Answering Point (PSAP) uses the phone number of the caller to look up the caller information and billing address [4]. If a call is dropped, the operator at the PSAP can call back. This readily available information helps find and direct the closest police, fire, and medical agencies [4]. All this helpful information is shown on the PSAP's screen immediately. However, this same information is not available for wireless subscribers. In the wireless case, no address, phone number, closest police, or other information is available, and the PSAP operator has to get this information by asking the caller. In addition, the caller must frequently be transferred to another closer PSAP in order to obtain emergency services. If a cellular call drops during the conversation, the caller has to call again and gathering useful data about the caller's name and location has to begin from start. This is the primary reason for the FCC mandate. The E-911 capability, when implemented, will require no overt action by the user in order to be located [4]. The FCC E-911 mandate has been issued in two phases. Handset-based and hybrid methods were introduced in the re-issued Phase II requirements in September 1999. The new Phase II requires that wireless service providers identify the position of a mobile handset user calling E-911 within a radius of 50 meters for 67 percent of calls and 150 meters for 95 percent of calls. For network-based solutions, the requirement is 100 meters for 67 percent of calls and 300 meters for 95 percent of calls [5].

1.2 Geolocation Based Services

Wireless geolocation has a great number of applications called location-based services which can be defined as value added services that utilize the knowledge of the mobile user's geographical location [6]. This information is helpful and actually essential for a great number of reasons. It is useful to categorize the uses of geolocation in two groups:

Geolocation for Military and Geolocation for Civilian and Commercial purposes.

1.2.1 Geolocation for Military

Although the primary drive behind geolocation technology is the FCC mandate for E-911 safety purposes, it has many application areas in the military as well. Starting with battlefield, locating an infantry soldier or a vehicular unit and tracking them via a Command and Control Center may be achieved by means of wireless geolocation technologies. This capability in military wireless networks would enable Command and Control Centers to be fully informed about their units' positions. In addition, it would be easy to locate an injured soldier even when he couldn't speak. His cell phone, laptop or other wireless device could transmit the necessary location signal which would be used in order to provide his geographic location information. Another application area is the electronic surveillance of a network coverage area for security purposes.

1.2.2 Other Geolocation Services

Studies on how to implement geolocation have created another interesting research area which has many potential uses and applications for civilian, commercial purposes: Wireless Geolocation Services. As noted before, the primary use of geolocation is in locating emergency 911 callers for safety purposes. Other geolocation services could include:

- Roadside assistance : direction finding, mapping, navigation assistance, traffic information.
- Tracking: Both people such as children, seniors, mentally handicapped and even car or asset could be tracked.
- Intelligent transportation system applications such as fleet management.
- Automatic Crash Notification (ACN): reports a crash of an automobile to necessary places, such as fire and PSAP (Public Safety Answering Point).
- Location-based billing.
- Location based services: location specific information such as local weather, mobile yellow pages, etc.
- Mobile e-commerce, wireless advertising and instant messaging.

Wireless Geolocation can also help solve a network routing issue. Accurate routing is
an important performance issue in computer networks, especially in mobile ad hoc networks [7].

1.3 Background

There are a number of different geolocation technologies that have been proposed by people. These include, Assisted GPS (A-GPS), network-based technologies such as Enhanced Observed Time Difference (E-OTD), Cell of Origin (COO), Time

Difference of Arrival (TDOA), Time of Arrival(TOA), Angle of Arrival(AOA), and hybrid techniques.

1.4 Research Objectives

This research studies some of these techniques like TDOA, AOA, and hybrid techniques along with their strengths and weaknesses. The primary goal of this research is the evaluation of hyperbolic position location technique, angle of arrival technique and a hybrid of both in cellular environment.

1.5 Organization of the Document

This chapter gives a brief introduction to wireless networks and geolocation technologies. The goal of the research and organization of the document is also presented.

The second chapter presents an overview of literature of different approaches used in network-based geolocation technologies, i.e., E-OTD, TDOA, AOA, COO.

The third chapter talks about the Time Difference of Arrival (TDOA) technique. It talks about TDOA Estimation Techniques, Hyperbolic Position Location Estimation and Algorithms.

Chapter four presents Angle Of Arrival (AOA) Technique, the AOA estimation algorithm (MUSIC algorithm).

The fifth chapter presents the Hybrid Technique.

Chapter six presents the summary, conclusions drawn from the results of the research and the recommendations for future studies.

CHAPTER 2

Wireless Geolocation Technologies

2.1 Introduction

Wireless geolocation seeks to determine the position of a mobile user in a wireless network. It has attracted significant attention in recent years. So far, existing cellular networks have lacked this capability. The need to include geolocation technology into the wireless network is driven by two critical factors:

1. First and primarily, the FCC E-911 mandate requires that wireless service providers must identify the position of a mobile user calling 911 within a radius of 50 meters for 67 percent of calls and 150 meters for 95 percent of calls for handset-based solutions. For network-based solutions, location within 100 meters for 67 percent of calls and 300 meters for 95 percent of calls are the required location estimate errors [5].

2. The second factor is that many new types of commercial services are being developed to take advantage of a geolocation capability such as zone-based billing, mobile yellow pages, improved roadside assistance, personal direction finding, intelligent transport systems (e.g., fleet management and vehicle tracking), mobile directory assistance, and services for public safety and security [8].

Wireless geolocation technologies will be presented in three groups. First, network based geolocation technologies, next handset-based geolocation technologies and finally, hybrid technologies.

2.2 Wireless Geolocation Technologies

2.2.1 Network-based Geolocation Technologies

In network-based technologies, the cellular network uses the signals transmitted by the Mobile Station (MS) and calculates its position using those signals. Cell-Id method, Time of Arrival (TOA), Time Difference of Arrival (TDOA) and Angle of Arrival (AOA) fall into this category.

2.2.1.1 Cell Id Based Technique

Cell Id method is the simplest geolocation technology. With this technique, the MS's location is determined with the knowledge of its serving base station cell area. This method uses the basic position location capabilities that all the cellular networks have today. When a mobile phone is on, it is served by the nearest base station, and the cell area of that base station is used as the location of the MS. This method often incorporates Timing Advance (TA) information. TA is an estimate of the distance from the mobile to the base station using the measured time between the start of a radio frame and the arrival of bursts from the mobile station. This information is already built into the network and the accuracy is acceptable when the cells are small (a few hundred meters) [9]. For services where proximity is the desired information, this is a very inexpensive and useful method. It works with all existing terminals, which is a big advantage. This method, called Cell Global Identity-Timing Advance (CGI-TA) has been described and standardized [10]. The accuracy of this method depends upon size coverage of the cell i.e., the type of the cell that the MS is in.

In urban areas where the pico cells are deployed, the accuracy is between 100 and 200 meters. If the Timing Advance (TA) is applied, the accuracy again, depending on the cell size, varies from 10m (a microcell in a building) to 500m (in a large outdoors macrocell) [10].

2.2.1.2 Time Of Arrival(TOA) Technique

Absolute Time Of Arrival (TOA) for the signal from the handset to the base stations can be estimated in many ways. If the handset is able to stamp the current time on any outgoing signal, the base station can determine the time that the signal takes to reach the base station. Hence, the distance between the mobile and the base station can be determined.

$$R_i = c\, d_i$$

Where R_i is the range measurement, c is the signal propagation speed and d_i is the TOA estimate at the ith receiver. The mathematical relationships between range measurements at N base stations, the coordinates of the known base station locations, and the coordinates of the source are

$$R_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2} \quad for\ i = 1, 2, 3, \ldots N,$$

where (X_i; Y_i; Z_i) are the coordinates of the ith base station, R_i is the ith range estimate to the source and (x; y; z) is the location of the user.

If at least three different receivers can receive the signal from the mobile, the position of the mobile can be found. However, this requires a very accurate timing reference at the mobile which would need to be synchronized with the clock at the base stations. Clearly, this solution is very difficult to achieve, as having an accurate and synchronized clock in the mobile is a difficult technical challenge and would again result in increased cost and size of the mobile handset.

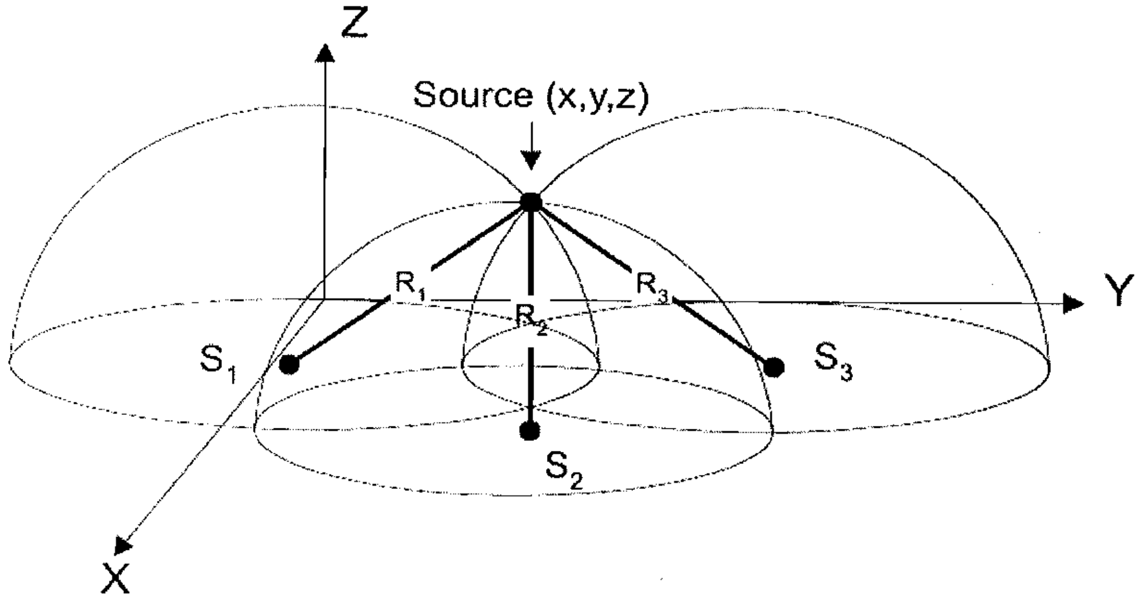


Figure 2.1 : 3-D Ranging Position Location Solution

A disadvantage of the ranging PL technique is that accuracy is very dependent on system geometry. Highest accuracies are attained when all ranging spheres intersect at 90 degrees. Degradation in performance is experienced as the intersections deviate from this angle. For systems with fixed receivers and moving sources, such as cellular and PCS systems, the optimum situation will rarely be attained. Another disadvantage of this PL technique is that the errors in the TOA estimate common to all receivers are not treated before the position location estimate.

Elliptical PL Systems

Elliptical PL systems locate a source by the intersection of ellipsoids describing the range sum measurements between multiple receivers. Figure illustrates the 2-D solution of an elliptical location system. The range sum is determined from the sum of signal TOA's at multiple receivers. The relationship between range sum, $R_{i,j}$, and the TOA between receivers is given by

$$R_{i,j} = c\, d_{i,j} = R_i + R_j$$

where c is the signal propagation speed and $d_{i,j}$ is the sum of TOA at receiver i and j. The range sum measurement restricts the possible source locations to a ellipsoid. The ellipsoids that describe the range sum between receivers is given by

$$R_{i,j} = \sqrt{(X_i - x)^2 + (Y_i - y)^2} + \sqrt{(X_j - x)^2 + (Y_j - y)^2},$$

where (X_i, Y_i, Z_i) and (X_j, Y_j, Z_j) define the location of receiver i and j, and (x,y,z) is the position location estimate of the source. A source location can be uniquely determined by the intersection of three or more ellipsoids. Redundant range sum measurements can be made to improve the accuracy and resolve location solution ambiguities. This method offers the advantage of not requiring high precision clocks at the mobile. While there exist some systems that use this method, it appears that it offers no performance advantage over the spherical or hyperbolic configurations.

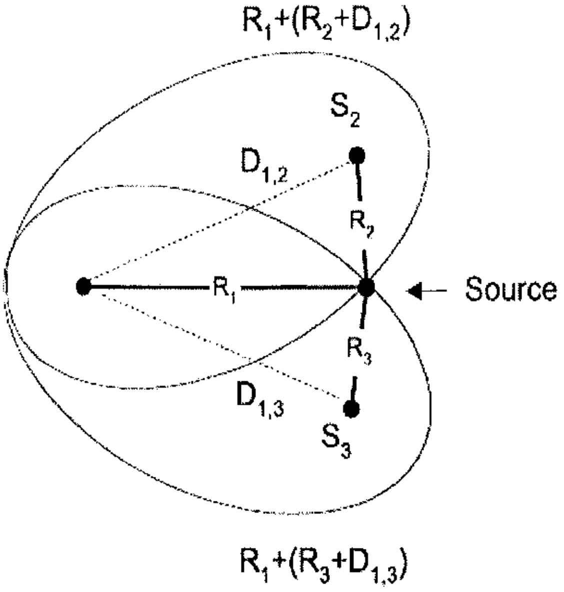


Figure 2.2 : 2-D Elliptical Position Location Solution

2.2.1.3 Time Difference of Arrival (TDOA) Technique

The principle of TDOA is to determine the relative position of the MS by measuring the time differences at which the signal transmitted by the MS arrives at multiple base station receivers, rather than using the absolute arrival time [8]. Assuming radio waves travel at a constant rate of 300,000 km/s, and using the difference in arrival times, it is possible to calculate hyperbolas on which the MS is located. The equation of the hyperbolas is

$$R_{i,j} = c(t_i - t_j) = d_i - d_j$$

$$R_{i,j} = \sqrt{(X_i - x)^2 + (Y_i - y)^2 + (Z_i - z)^2} - \sqrt{(X_j - x)^2 + (Y_j - y)^2 + (Z_j - z)^2}$$

where t_i and t_j are the Time of Arrival(TOA) estimates of the signals from base stations i and j, d_i and d_j are the distances from the mobile to base stations i and j, c is the speed of light, (X_i ,Y_i ,Z_i) and (X_j ,Y_j ,Z_j) denote the coordinates of the base stations and (x; y; z) is the unknown coordinate of the mobile station. At least three base stations are required in order to obtain a location estimate. Studies show that if more than three base stations are involved in measurements, more accurate location estimates are achieved [12].

2.2.1.4 Angle of Arrival (AOA) Technique

The Angle of Arrival method uses simple triangulation based on estimated Angle of Arrival (lines of bearing) of a signal at 2 or more base stations to estimate the location of the MS. The most common version of this technique is known as small aperture direction finding which requires a complex of 4-12 antenna arrays in a horizontal line at each of several cell site locations. The antennas work together to determine the angle from which a signal originated. When several sites can each determine their respective angles of arrival, the location of the MS can be estimated from the point of intersection of projected lines drawn out from the cell site at the angle which the signal originated.

The most significant disadvantage with the AOA technique is the cost of installing antenna arrays. Although adaptive antenna arrays increase the capacity of cellular systems, they would only be needed in the areas where the capacity enhancement will be required. Thus, it is impractical to install antenna arrays at every cell site for the purpose of geolocation. The disadvantages are that it shows very poor performance in rural areas because of the linear orientation of base stations along major roads and requires adding expensive and complex antenna arrays. A small angular error of the antenna array can produce a significant error in location estimate. Furthermore, in the absence of a LOS signal component, the antenna array will lock on to a reflected signal component and, even if a LOS is present, multipath propagation will cause errors with the angle measurements.

2.2.2 Handset-based Geolocation Technologies

The most widely known position location system is the Global Positioning System (GPS). The GPS is a satellite-based pseudo-ranging position location system that provides geolocation of user's with GPS receivers. The GPS is a proven technology that has found widespread use in military and navigation applications. It can reportedly provide position location accuracy's of less than 10 meters to military users and 100 meters to commercial users [13]. Although GPS has found wide acceptance in these applications, the use of GPS for the geolocation of mobile users within cellular and PCS system is limited [13]. Most importantly, use of GPS for the geolocation of mobile users would require a mobile user to have a GPS receiver. At the present time, GPS receivers are not cheap enough or small enough to be incorporated into a mobile phone. Even if they were, mobile phone manufacturers may hesitate to include GPS receivers because of the added weight, size, power consumption and cost.

2.3 Summary

Direction finding and range-based RF PL systems have been the most widely used position location techniques. Each method offers unique advantages and disadvantages to the geolocation of mobile user's. Direction finding systems can provide accurate PL estimation; however, they are usually very complex and are susceptible to multipath environments. Ranging PL systems require additional hardware or software within the mobile phone, and encounter ambiguity problems. Elliptical PL systems do not offer any advantage over ranging or hyperbolic PL systems. The hyperbolic PL technique has been the most widely used method for the geolocation of mobile users. Hyperbolic PL systems do not require implementation within the mobile phone, are able to provide unambiguous PL solutions and can reduce the effect of errors introduced by noise that is common to all receivers. While each systems offers advantages and disadvantages, hyperbolic position location systems are more effective in combating the elements associated with mobile radio channels.

CHAPTER 3

Time Difference of Arrival (TDOA) Position Location Technique

3.1 Introduction

This chapter introduces the general models for the position location problem. After that the different techniques involved in the hyperbolic position location method have been looked at. Firstly, the time difference of arrival (TDOA) between receivers through the use of time delay estimation techniques is estimated. The estimated TDOA's are then transformed into range difference measurements between base stations, resulting in a set of nonlinear hyperbolic range difference equations. After that the algorithms to produce an unambiguous solution to these nonlinear hyperbolic equations are used. The solution produced by these algorithms result in the estimated position location of the source.

Position Calculation with TDOA

As mentioned earlier, TDOA is a hyperbolic position location estimation technique. The location estimation using TDOA is achieved in two stages. First, the time differences from MS and BSs (TDOAs) are estimated and in the second stage, estimated TDOAs are transformed into a set of nonlinear hyperbolic equations, which upon solving will provide the estimated position of the MS. Since the equations derived are non-linear, solution of those hyperbolic equations require use of efficient algorithms. In this section, a survey of different techniques and algorithms which may be used in TDOA estimation and solving hyperbolic nonlinear equations is provided.

3.2 TDOA Estimation Techniques

The TDOA of a signal can be estimated by two methods:

- subtracting TOA measurements from two base stations to produce a relative TDOA,
- through the use of cross-correlation techniques, in which the received signal at one base station is correlated with the received signal at another base station.

Cross-correlation techniques are used extensively in estimating the TDOA. Two different cross-correlation techniques are used; distributed and centralized. In the former method, a cross-correlation is done at every base station, in the second method, every signal pattern from every base station is compared and correlated to a reference base station. The reference base station is the first base station which receives the signal from the MS.

3.2.1 Generalized Cross-Correlation Technique

A mathematical model for cross-correlation is presented below. Assuming a Gaussian-like channel with interference and noise and a signal s(t) being transmitted from a MS, a general mathematical model for the time-delay estimation between signals at two base stations BS1(t) and BS2(t) can be written as:

$$BS1(t) = A_1 * s(t - d_1) + n_1(t)$$

$$BS2(t) = A_2 * s(t - d_2) + n_2(t)$$

where A1 and A2 correspond to the amplitudes of the signals at base stations, n1(t) and n2(t)

are noise and d1 and d2 correspond to signal delay (arrival) times. It is assumed that s(t), n1(t) and n2(t) are zero-mean (time-average) random processes and s(t) is independent from n1(t) and n2(t). Assuming that BS1 is the reference base station (d1 < d2) the equations can be rewritten:

$$BS1(t) = s(t) + n_1(t)$$

$$BS2(t) = A * s(t - D) + n_2(t)$$

where $A = A_1/A_2$ and $D = d_2 - d_1$

An estimated cross-correlation function of these signals is:

$$R_{1,2}(t) = \frac{1}{T} \int_0^T S_1(t) * S_2(t + \tau) dt$$

where T represents the observation time. Once the cross-correlation function is computed at the reference BS, the value of t that maximizes the above equation provides the TDOA estimate.

3.2.2 Measures of TDOA Estimation Accuracy

The Cramer-Rao Lower Bound (CRLB) on the variance of an unbiased estimator is the standard benchmark against which conventional TDOA estimation methods are evaluated. The CRLB typically used is for evaluating stationary Gaussian signals in stationary Gaussian noise environments [12]. The BPSK PN signalling used in CDMA systems exhibit fundamental periodicities in the chip period, data period and PN code repetition period. The signal is therefore nonstationary (cyclostationary) and thus cannot be appropriately evaluated by the typical CRLB. Although the CRLB for nonstationary signals exist, but it is very difficult to evaluate.

3.3 Solving Non-linear Hyperbolic Equations

After the TDOA estimates are obtained, a set of non-linear hyperbolic equations is defined by transforming TDOAs into range difference measurements. Since these equations are non-linear, solving them is not a trivial procedure. The range difference between MS and base station is

$$R_{i,j} = \sqrt{(X_i - x)^2 + (Y_i - y)^2} - \sqrt{(X_j - x)^2 + (Y_j - y)^2}$$

these range differences are equal to TDOA delay(D), and using a reference base station, we can write

$$R_{i,1} = c * d_{i,1} = R_i - R_1 = \sqrt{(X_i - x)^2 + (Y_i - y)^2} - \sqrt{(X_1 - x)^2 + (Y_1 - y)^2}$$

where c is the speed of signal (approximately $3 * 10^8$m/s), $d_{i;1}$ is the TDOA estimate, R_i is the distance between the reference base station and mobile station and $R_{i;1}$ is the range differences between the first(reference) base station and the ith base station. These equations together define the set of nonlinear hyperbolic equations, and solving these equations will yield the estimated position of the MS in terms of x and y. In the remainder of the chapter, different algorithms have been proposed in order to solve these hyperbolic equations. They have different levels of complexity and yield different levels of accuracy. Three different methods are used: the Taylor-series method, Fang's method and Chan's method.

3.3.1 Taylor-Series Method

The Taylor-Series method linearizes the set of non-linear equations by Taylor-Series expansion and then iteratively produces a solution. The method requires an initial guess and improves the estimate at each iteration by determining the local linear least-squares (LS) solution. It benefits from extra measurements which is the case when there are more than three visible base stations. It is sensitive to the initial guess. The algorithm might not always converge under bad GDOP (Geometric Dilution Of Precision) circumstances. GDOP is a measure of how ranging error affects position error due to the geometry of base stations.

Analytical Model for Taylor's Method

With a set of TDOA estimates $d_{i,1}$, the method starts with an initial guess (x0; y0) and computes the deviations of the location estimates using the below formula called as minimum variance estimation formula:

$$\begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} = (G_t^T Q^{-1} G_t)^{-1} G_t^T Q^{-1} h_t$$

where Q is the equation error covariance matrix of the TDOA estimates,

$$h_t = \begin{bmatrix} r_{2,1} - (r_2 - r_1) \\ r_{3,1} - (r_3 - r_1) \\ \dots\dots\dots\dots\dots \\ r_{n,1} - (r_n - r_1) \end{bmatrix}$$

$$G_t = \begin{bmatrix} (X_1 - x)/r_1 - (X_2 - x)/r_2 & (Y_1 - y)/r_1 - (Y_2 - y)/r_2 \\ (X_1 - x)/r_1 - (X_3 - x)/r_3 & (Y_1 - y)/r_1 - (Y_3 - y)/r_3 \\ \dots\dots\dots\dots\dots\dots\dots\dots & \dots\dots\dots\dots\dots\dots\dots\dots \\ (X_1 - x)/r_1 - (X_n - x)/r_n & (Y_1 - y)/r_1 - (Y_n - y)/r_n \end{bmatrix}$$

The values r_i= 1,2,...n are computed using

$$r_i^2 = (X_i - x)^2 + (Y_i - y)^2$$

where initially x = x_0 and y = y_0. In the next iteration x_0 and y_0 are set to $x_0 + \Delta x$ and $y_0 + \Delta y$ and this iterative process is repeated until Δx and Δy are sufficiently small.

3.3.2 Fang's Method

Fang's non-iterative algorithm gives an exact solution only when the number of TDOA measurements are equal to the number of unknowns (coordinates of MS). Although the algorithm works well when the base stations are placed arbitrarily, it cannot make use of redundant measurements such as when there are more than three base stations available to improve position accuracy.

3.3.3 Chan's Method

Chan's method, is also a non iterative algorithm that solves the problem by producing a closed-form solution valid for both distant and close sources. The method produces its most accurate results when the TDOA errors, i.e., noise levels are small. For three base stations with two TDOA estimates, x and y can be solved in terms of R1 using

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} X_{2,1} & Y_{2,1} \\ X_{3,1} & Y_{3,1} \end{bmatrix}^{-1} \times \left(\begin{bmatrix} R_{2,1} \\ R_{3,1} \end{bmatrix} * R_1 + \frac{1}{2} \begin{bmatrix} R_{2,1}^2 - K_2 + K_1 \\ R_{3,1}^2 - K_3 + K_1 \end{bmatrix} \right)$$

where

$$K_1 = X_1^2 + Y_1^2,$$

$$K_2 = X_2^2 + Y_2^2,$$

$$K_3 = X_3^2 + Y_3^2.$$

After solving the equation in R1, substitute x and y into

$$R_i = \sqrt{(X_i - x)^2 + (Y_i - y)^2}$$

at i = 1 which gives us a quadratic in R1. By substituting R1 back into the first equation, the solution is obtained. Sometimes, there may be two positive roots that produce two different answers; however, the ambiguity can often be resolved by restricting the mobile station's position to within the area of network coverage.

3.4 Summary

In this chapter, the techniques used in hyperbolic position location have been explained. A detailed description of the techniques used to evaluate the hyperbolic non-linear equations has been presented.

CHAPTER 4

Angle Of Arrival (AOA) Technique

4.1 Introduction

AOA methods are also referred to as Direction of Arrival (DOA) methods. AOA methods utilize multi-array antennas and try to estimate the direction of arrival of the signal of interest. Thus a single DOA measurement restricts the source location along a line in the estimated DOA. If at least two such DOA estimates are available from two antennas at two different locations, the position of the signal source can be located at the intersection of the lines of bearings from the two antennas. Usually multiple DOA estimates are used to improve the estimation accuracy by using the redundant information. Figure below shows the method where the source location is found by the intersection of DOA of the signal for three antenna arrays.

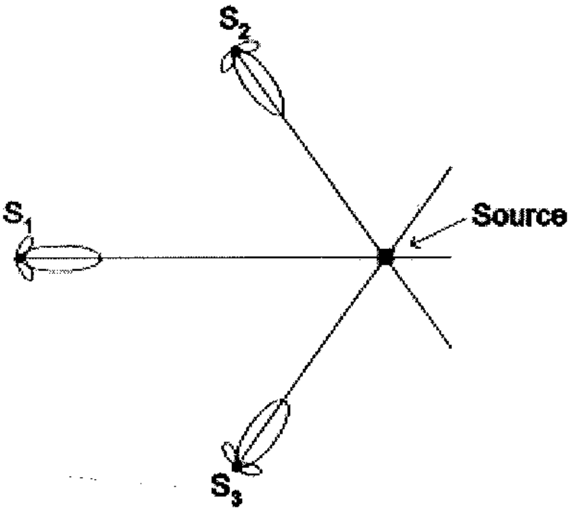


Figure 4.1 : 2-D Direction Finding Position Location Solution [1]

To estimate the DOA, algorithms are used that exploit the phase differences or other signal characteristics between closely spaced antenna elements of an antenna array and employ phase-alignment methods for beam/null steering. The spacing of antenna elements within the antenna array is typically less than 1/2 wavelength of all received signals. This is required to produce phase differences on the order of π radians or less to avoid ambiguities in the DOA estimate. The resolution of DOA estimates improves as the baseline distances between antenna elements increase. However, this improvement is at the expense of ambiguities. As a result, DOA estimation methods are often used with short baselines to reduce or eliminate the ambiguities and at other times with long baselines to improve resolution.

Although DOA methods offer a practical solution for wireless position location, they have certain drawbacks. For accurate DOA estimates, it is crucial that the signals coming from the source to the antenna arrays must be coming from the Line-Of-Sight (LOS) direction. However, this is often not the case in cellular systems, which may be operating in heavily shadowed channels, such as those encountered in urban environments. Another factor which is the considerable cost of installing antenna arrays. Although adaptive antennas hold considerable promise for improving the capacity of cellular systems they would only be needed in the areas where capacity enhancement will be required. Hence, for rural and suburban areas which are sparsely populated, this would be a costly solution to meet the E-911 requirements. Even if antenna arrays are in place at some base stations, the position location system may need regular calibration since a minute change in the physical arrangement of the array because of winds or storms, may result in considerable position location error as the absolute angular position of the array is used as a reference for the AOA estimates. This is a problem that would be unique to position location as this will not affect the interference rejection capability of the array. Hence, if the arrays are to be used for position location they would either need extremely rugged installation or some other method of continuous calibration for accurate DOA estimates. Another problem with this method is the complexity of the DOA algorithms.

4.2 Base Station Antenna Arrangement

An antenna for a base station comprising a plurality of antenna arrays each capable of forming a multiplicity of separate overlapping narrow beams in azimuth, the arrays being positioned such that the beams formed by the arrays provide a coverage in azimuth wider than each array.

This invention relates to a base station antenna arrangement, for use in a Cellular Radio communications system, which shall hereafter be referred to as a smart antenna. Cellular radio systems are currently in widespread use throughout the world providing telecommunications to mobile users. In order to meet the capacity demand, within the available frequency band allocation, cellular radio systems divide a geographic area to be covered into cells. At the centre of each cell is a base station, through which the mobile stations communicate. The available communication channels are divided between the cells such that the same group of channels are reused by certain cells. The distance between the reused cells is planned such that the cochannel interference is maintained at a tolerable level. When a new cellular radio system is initially deployed, operators are often interested in maximising the uplink (mobile station to base station) and downlink (base station to mobile station) range. The ranges in many systems are uplink limited due to the relatively low transmitted power levels of hand portable mobile stations. Any increase in range means that less cells are required to cover a given geographic area, hence reducing the number of base stations and associated infrastructure costs. When a cellular radio system is mature the capacity demand can often increase, especially in cities, to a point where more, smaller size cells are needed in order to meet the required capacity per unit area. The process used to create these smaller cells is known as cell splitting. Any technique that can provide additional capacity without the need for cell-splitting will again reduce the number of base station sites and associated infrastructure costs. The antenna used at the base station site can potentially make significant improvements to the range and capacity of a cellular radio system. The ideal base station antenna pattern is a beam of narrow angular width as shown in Figure 4.2.

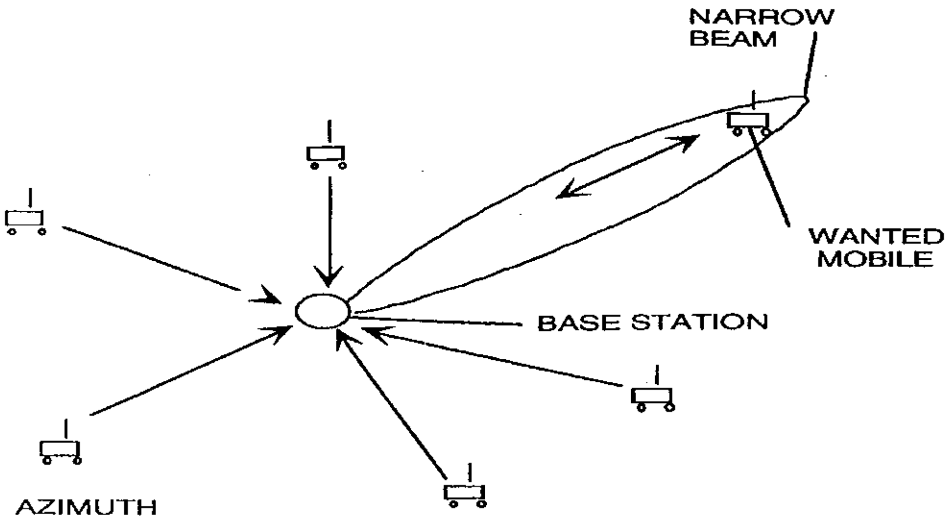


Figure 4.2 : Ideal Base Station Antenna Pattern [17]

The narrow beam is directed at the wanted mobile, is narrow in both the azimuth and elevation planes, and tracks the mobile's movements. When compared to an omni-directional antenna, such a beam will have the dual benefits of having high gain, leading to increased range in thermal noise limited initial deployments, and rejecting interference from co-channel reuse cells allowing higher capacity with-out cell splitting in mature deployments. The narrow beam reduces interference in a balanced manner on the uplink and downlink. On the uplink the base station receiver is protected from interference generated by mobile station transmitters in the co-channel reuse cells, as shown in figure 4.3.

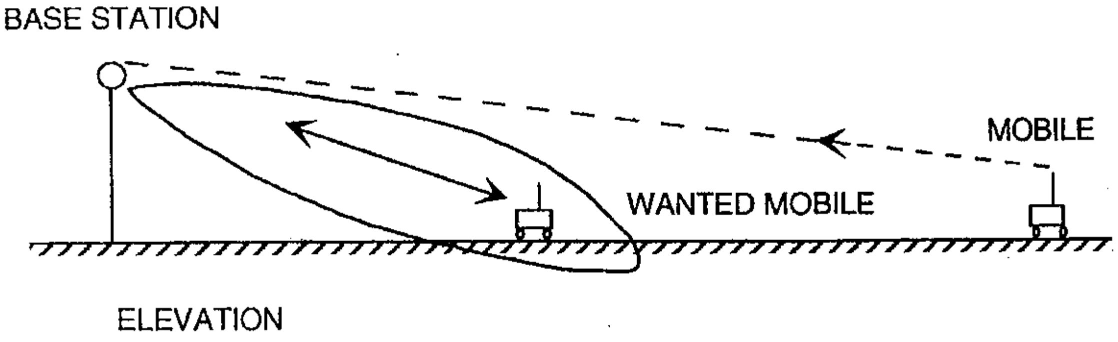


Figure 4.3: Base Station Receiver [17]

On the downlink the mobile is unlikely to be in the beams of the base station transmitters in the co-channel reuse cells. The extent of the advantage of a narrow beam antenna over an omni- directional antenna is a function of the beamwidth. The narrower the beamwidth the greater the advantage, but this must be traded off against the increased size and complexity of the antenna. Although the narrow beam is formed at radio frequencies (typically in the 900 or 1800 MHz bands) it can usefully be visualised as analogous to a laser beam that emanates from the base station and tracks the mobiles. When contrasted with an omni-directional antenna, this clearly creates a high quality transmission path with minimal interference. Within current systems the manner in which directive antennae are used allows relatively small benefits to be obtained. The use of directive antennas in current cellular radio systems is based on the principle of sectorisation as illustrated in Figure.4.5. The main sources of interference, in a cellular system, come from the so called first tier reuse cells. An omni-directional base station antenna will receive interference from all six first tier reuse cells.

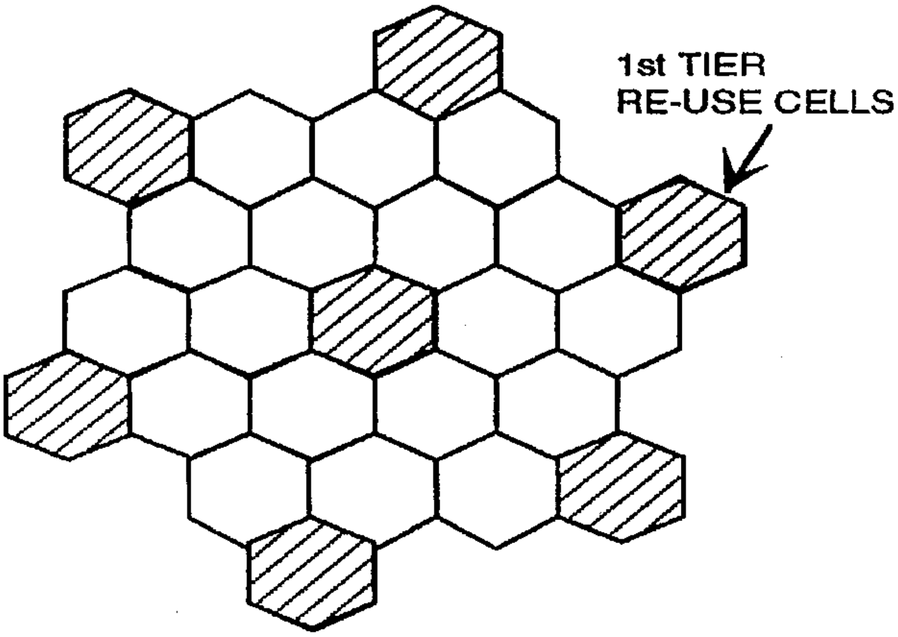


Figure 4.4 : Omni Directional Configuration

(N =7 Re Use Factor) [17]

If an antenna with nominally 120° beamwidth is used, corresponding to a tri-sectored configuration, interference will be received from only two first tier reuse cells,

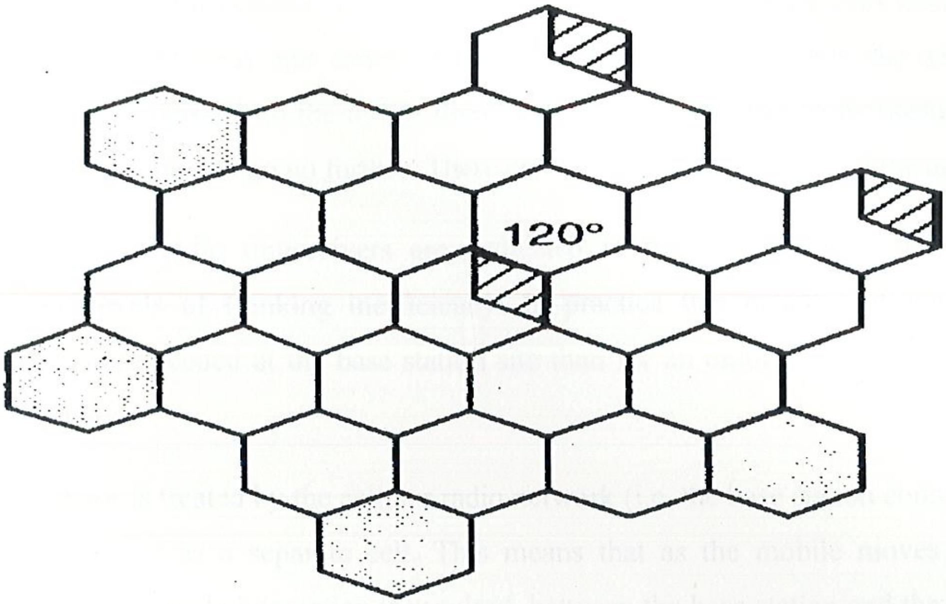


Figure 4.5 : Typical Tri-Sectored Configuration

(N=7 Re-Use Factor) [17]

If an antenna with 60° beamwidth is used, corresponding to a hex-sectored configuration, inter-erence will be received from only one of the first tier cells,

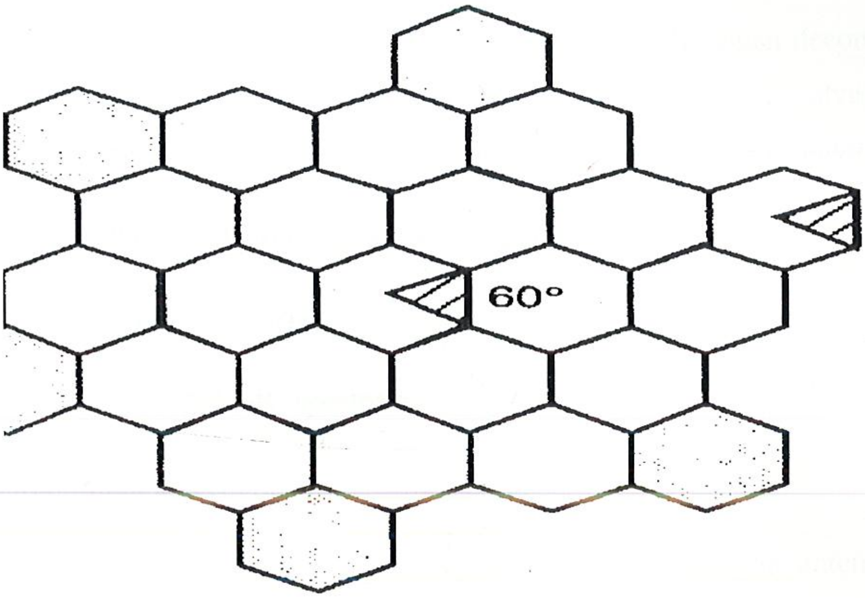


Figure 4.6 : Typical Hex-Sectored Configuration

(N=7 Re-Use Factor) [17]

In sectorised cells the cellular radio transceivers at the base station are only connected to one sector (or antenna) and cannot be used in other sectors within the same cell. The sectorised approach to the use of directive antennas has reached its useful limit at 60° beamwidth and can go no further. There are two key disadvantages of the approach:

a) The cellular radio transceivers are dedicated to particular sectors that leads to significant levels of trunking inefficiency. In practice this means that many more transceivers are needed at the base station site than for an omni-directional cell of the same capacity.

b) Each sector is treated by the cellular radio network (i.e. the base station controller and mobile switches) as a separate cell. This means that as the mobile moves between sectors, a considerable interaction is required, between the base station and the network, to hand off the call, between sectors of the same base station.

4.3 Calculating the Estimates

4.3.1 Music Algorithm

The MUSIC algorithm is a kind of directional of arrival (DOA) estimation technique based on eigen value decomposition, which is also called the subspace-based method. Here, we consider a unitary MUSIC algorithm. With this, the eigen decomposition of correlation (covariance) matrix in the MUSIC algorithm can be solved with real numbers only. The unitary MUSIC computational flow involves the following steps:

1. Estimation of the correlation matrix, including unitary transform.

2. EVD of the correlation matrix.

3. Computation of the MUSIC spectrum.

4. Local Maximum detection.

The aim is to implement the MUSIC algorithm that enables an antenna array to estimate the number of incident signals on the array and their directions of arrival. Let there be m elements in the array. Let xi be the input at the ith element of the array (including noise added by the instruments and present in incoming signal) and let x =[xi]. According to the MUSIC algorithm, the covariance matrix formed as S = xx* (where x*denotes conjugate transpose) has n repeated minimum eigen-values (for uncorrelated noise) that represent the variance of the noise. The number of incident signals is given by d = m−n. Further, the eigenvectors corresponding to these eigen-values are orthogonal to the array manifold (the gain and phase change provided by the array elements to the incoming signal directions) at the values of the incoming signal directions. Hence, on forming a matrix E_N of these eigenvectors and plotting PMU(□) =1/a(□)*$E_N E_N$* a(□) we get peaks at the values of theta corresponding to the incoming signal directions.

I: This part is a sample calling program designed to validate the working of the music algorithm. A real life case will be considered later. The sample program is simulating a sine wave input that is arriving at the array in the form of planar wavefronts (the source is assumed sufficiently far away). The array itself is assumed to be an m (NO OF ELEMENT) element linear array with no directional properties (could be an array of dipoles) in the given plane. The number of elements can be varied. Further the frequency of the input can be changed. dfactor is the division factor of the wavelength that represents the distance between the elements (for eg: if dfactor = 2 ,distance between elements = $\lambda/2$). Thus we have a handle on both the frequency and the distance between elements in terms of the given frequency. The samples variable represents the number of samples that we wish to take for the given input and f_s represents the sampling frequency. These two variables can be adjusted to simulate the processor available, the amount of accuracy and the system refresh rate. For example , if we chose a high value of samples , amount of memory utilisation increases and the refresh rate (rate between consequent measurements) decreases however the accuracy of calculations increases (assuming input signal lasts for that long a time).

II: The array manifold is defined as the gain and phase change provided by the array elements to a given signal direction. The array manifold is a function of □ and is saved in the file manifold file. Note that the variables NOOFELEMENTS and dfactor are global and hence can be accessed by the manifold too.

III: This part consists of the actual implementation of MUSIC algorithm. The function returns an estimate of the dir3ection of arrival. It takes as input the x matrix. From the x matrix, the number of elements and the samples is obvious. The first step is the calculation of the covariance matrix. The next step involves calculation of the eigenvalues and eigenvectors of S.

On knowing the minimum eigenvalue, the multiplicity of this eigenvalue is obtained. The multiplicity is presently being obtained using a, naive comparison (refer to the code listing). However, the final aim is to use the MDL criterion to find the number of incident signals. The next step is to obtain the noise eigenvector matrix of these minimum eigenvalues and form the matrix. Using this matrix, we can plot to get direction of arrival in either a single dimension or multiple dimensions.

The program presented works only for a planar angle. The final aim is to get direction of arrival in terms of azimuthal angle and elevation angle.

4.3.1.1 Parameters

There are a number of **parameters** for which changes can be made and varying results can be obeserved. They are,

1. Number of elements: Increasing the number of elements increases the resolution for multiple sources. If the number of signals is large, then a higher element array predicts the directions of arrival better.

2. Noise: With lower noise, the peaks become sharper. The presence of added noise causes a spreading effect on the peaks.

3. Number of samples: Increasing the number of samples does not bring about a greater improvement in the plots. However, number of samples must be greater than number of incident signals for workable results. 100 samples work well for a 15-element array.

4. Distance between elements: The distance between elements can be changed. This effectively means that for a fixed frequency of the input wave, the centre frequency is changing that is the frequency at which the detection is best. A lower wavelength and hence higher frequency gives no resolution at all. On the other hand, a higher wavelength (lower frequency) gives a lot of spurious peaks. It is observed that for best detection of given frequency the distance between elements must be 2.

5. Kind of input wave: The kind of input wave can be varied. Results were verified for sine waves and FM-modulated waves. The plots obtained match those in theory. However the algorithm could not detect sin waves even on removing the DC offset of the waves.

6. Obtain 2-d direction: We can also extend the MUSIC algorithm to 2-d with the two dimensions being the plane angle and the elevation angle respectively. However the results obtained in 2-d are not so encouraging in terms of the number of peaks obtained.

4.4 AOA Distributions

The probability density functions are observed in different environments at the cellular base station (mobile).These probability densities are computed based on a "geometrical model" wherein omni-directional scatterers are modelled as spatially distributed at an inverted parabolic spatial distribution on a two-dimensional disc centered at the mobile, or based on "geometrical model" of the three-dimensional (3-D) spatial relationships among the mobile station, the scatterers, and the base station where The scatterers are herein modelled to have a uniform 3-D spatial distribution in an aboveground hemisphere with a flat circular base (or alternatively, within a sphere) centered at the mobile.

4.4.1 AOA Distributions with Scatterers in a 3-D Hemispheroid Surrounding the Mobile

A signal, transmitted from a mobile user in a landmobile radiowave wireless cellular communication system, arrives at the cellular base station through multiple propagation multipaths. Each multipath carries its own propagation history of electromagnetic reflections and diffractions and corruption by multiplicative noise—a history reflected in that multipath's amplitude, Doppler, arrival angle, and arrival time delay at the receiving antenna(s). The values of these amplitudes, Doppler frequency shifts, arrival angles, and arrival time delays depend on the electromagnetic properties of and the spatial geometry among the mobile transmitter, the scatterers, and the receiving antennas. Each receiving antenna's data measurement sums these individually unobservable multipaths.

The two-dimensional (2-D) azimuth-elevation angle of arrival (AOA) determines the angular spread and spatial decorrelation across the spatial aperture of an receiving antenna. The multipaths' nonzero elevation AOAs are most common in urban areas or over hilly terrains or with low-lying receiving antennas, where the propagating wave reflects off vertical structures like buildings or hills. The nonzero elevation AOA is critical for the use of a vertical or planar receiving antenna array.

"Geometric modelling" idealizes the aforementioned wireless propagation environment via a geometric abstraction of the spatial relationships among the transmitter, the scatterers, and the base station. Geometric models thus attempt to embed measurable fading metrics integrally into the propagation channel's idealized geometry, such that the geometric parameters would affect these various fading metrics in an interconnected manner to reveal conceptually the channel's underlying fading dynamics.

Geometric modelling contrasts with site-specific/terrain-specific/ building-specific empirical measurements or ray-shooting/ ray-tracing computer simulations, which are applicable only to the one particular propagation setting under investigation but cannot be easily generalized to wider scenarios. One geometric model can apply for a wide class of propagation settings, producing the received signal's measurable fading metrics (e.g., the uplink and downlink probability density functions of the multipaths' arrival delay and 2-D arrival angle as in this paper) applicable generally within that class of channels.

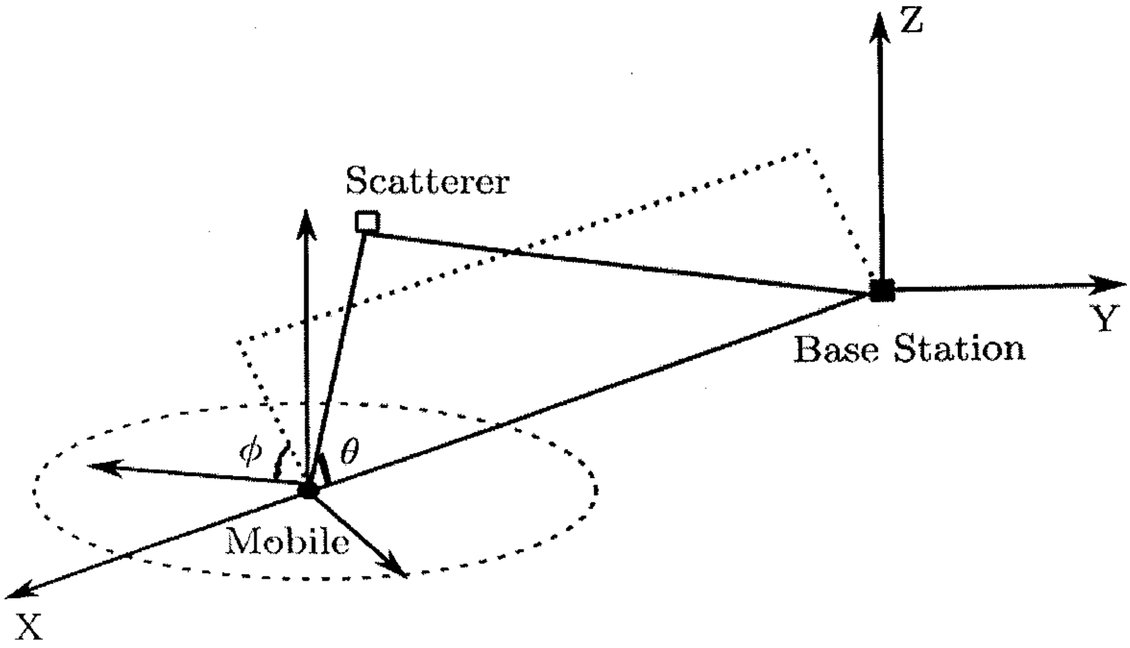


FIGURE 4.7 : 3-D geometry relating the mobile transmitter, scatterers environment [18]

Figure 4.7 shows the 3-D geometry relating the mobile transmitter, the scatterers, and the base station. The mobile is separated from the base stations by the distance D. Though only one scatterer is shown in the figures for graphical clarity, many scatterers exist; and the results herein derived apply to the ensemble of all scatterers. The scatterers are distributed only in a hemispherical spatial region surrounding the mobile transmitter, uniformly with $F(x,y,z)=3/2\pi R^3$ inside the hemisphere and $F(x,y,z)=0$ outside, where the spherical radius R is smaller than the distance D between the mobile and the base station.

Propagation-modelling assumptions AOA distributions based on geometrical models

1) Each propagation path, between the mobile and the base station, reflects off exactly one scatterer.

2) Each scatterer acts as an omnidirectional lossless retransmitter, independently of other scatterers.

3) Complex-phase effects in the receiving-antenna's vector summation of the arriving multipaths may be overlooked. That is, all arriving multipaths arriving at each receiving antenna are assumed to be temporally in-phase among themselves.

4) All antennas are isotropic, at both the base station and the mobile.

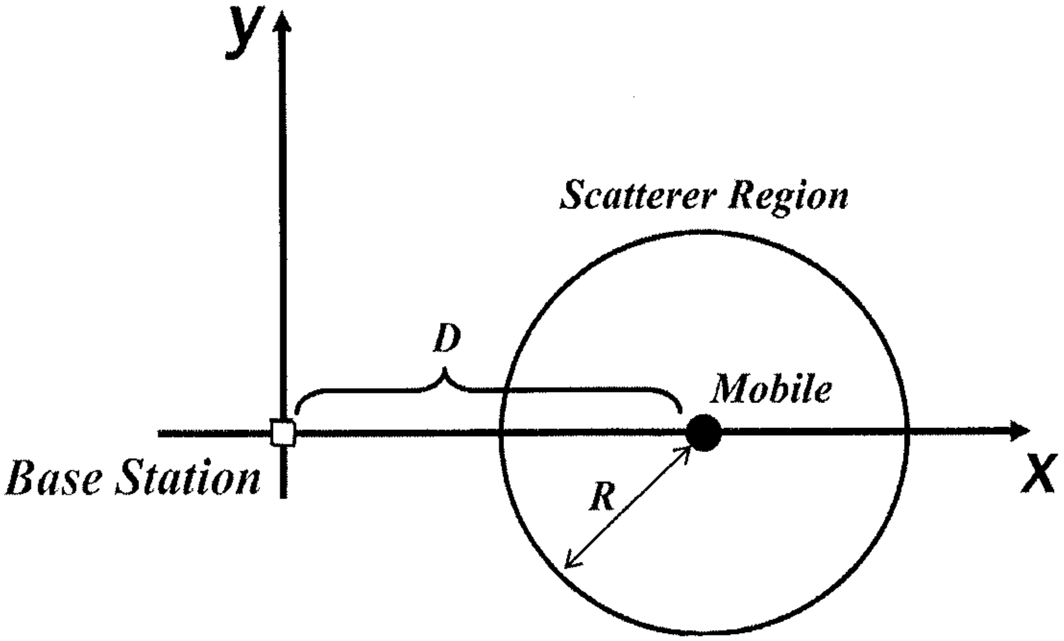


Figure 4.8 : Mobile and Base Station in Scatterers Environment [18]

The 2-D-AOA distribution of $(\emptyset, \theta)$ is

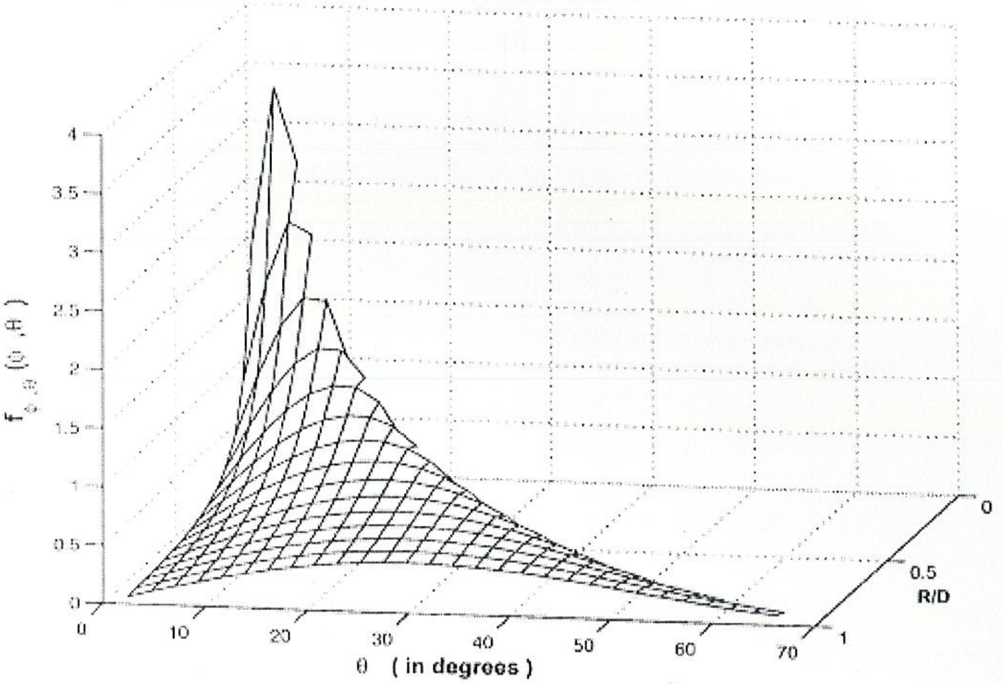


Figure 4.9 : 2-D-AOA distribution

4.5 Summary

In this chapter the Angle of Arrival technique was discussed. The Base station Antenna arrangement and the Ideal Base Station Antenna Pattern were looked at. It was seen that a narrow beam antenna gives a higher performance over an omni-directional antenna due to lower interference from adjoining cells. The narrow beam is directed at the wanted mobile, is narrow in both the azimuth and elevation planes, and tracks the mobile's movements, this clearly creates a high quality transmission path with minimal interference. The main sources of interference, in a cellular system, come from the so called first tier reuse cells. An omni-directional base station antenna will receive interference from all six first tier reuse cells. To remove these flaws the sectorized approach was discussed. To calculate the estimates the Music Algorithm was studied .The parameters used in Music Algorithm were mentioned. Finally the AOA distributions in 3-D Hemispheroid Surrounding the Mobile Model was studied in the scatterers environment.

CHAPTER 5

Hybrid TDOA/AOA Position Location Technique in CDMA Systems

5.1 Introduction

The third-generation (3G) wireless systems are currently under development around the globe and will be deployed soon. The current Radio Transmission Technology proposals for 3G wireless mobile systems employ wideband code-division multiple-access (CDMA) technology. The systems will offer a wide range of multimedia communication services and user location service. The previous work on MS location mainly aimed at the first and second-generation wireless systems. The main challenge is to achieve high location accuracy at low implementation cost, taking account of the hostile wireless propagation environment. Various wireless location schemes which have been extensively investigated (as also discussed in Chapter 2) can be classified to two categories: 1) time based location, where the time of arrival (TOA) or the time difference of arrival (TDOA) of the incoming signals is measured and 2) angle based location, where the angle of arrival (AOA) of the received signals is measured. Both categories have their own advantages and limitations. For example, TDOA schemes require at least three properly located base stations (BSs) for two-dimensional (2-D) MS locations, and generally have better accuracy than AOA schemes; AOA schemes, on the other hand, requires only two BSs minimum for a location estimate. However, it is highly range dependent. A small error in the angle measurement will result in a large location error when the MS is far away from any BSs involved. The solution to TDOA equations is obtained by linearizing the equations via a Taylor-series expansion [1] [4] [5]. The Taylor-series approach can achieve high accuracy, but requires an initial location guess and may suffer from the convergence problem if the initial guess is not accurate enough. Furthermore, it is an iterative approach and is computationally intensive as it needs to determine the local linear least-square (LS) solution in each iteration. To overcome the drawbacks, a two-step LS estimator for the TDOA location has been proposed [6]. The LS estimator is an approximation of the maximum-likelihood (ML) estimator when the TDOA measurement errors are small, and is able to provide a near optimum solution [2]. As TDOA and AOA location methods complement each other in most BS layouts, in this paper, we propose a hybrid TDOA/AOA location scheme which combines TDOA location with AOA location. The discussed location scheme has the advantages of both TDOA and AOA methods to achieve high location accuracy. For location estimator, the two-step LS estimator originally developed for TDOA location has been used to obtain the solution of the nonlinear TDOA/AOA location equations. Numerical results are obtained to demonstrate the high location accuracy of the proposed scheme. In Section II, description of the wideband CDMA system model under consideration has been given. Section III proposes the hybrid TDOA/AOA location scheme for the system. Section IV gives the derivation of the LS estimator for the TDOA/AOA location. The performance of the scheme is evaluated via computer simulation in Section V, followed by the conclusion in Section VI.

5.2 The Wideband CDMA System Model

A macrocell wideband CDMA system with frequency division duplex has been assumed. The system has the following characteristics: 1) BSs are precisely synchronized in time based on the global positioning system (GPS) time reference to facilitate accurate TDOA measurements in the forward link. In the cdma2000 [7] and Global CDMA I [10] proposals, network synchronous mode (where the BSs are synchronized to each other in time) has been fundamentally made to reduce the system complexity and to make the soft handoff schemes convenient. Even though the proposals from Europe [8], Japan [9], and Korea [11] adopt network asynchronous mode, it is specifically indicated in these proposals that "synchronous operation is also possible"; 2) similar to the 3G system proposals, a dedicated reverse-link pilot channel is assigned to each active MS to facilitate the initial acquisition, time tracking, coherent reference recovery, and power-control measurements for the MS. The BS serving a particular MS is called the home BS for that MS. The reverse pilot signal from the MS is sent in a continuous waveform to its home BS and is power controlled by the BS; 3) each BS is equipped with antenna arrays for adaptive beam steering. This allows the BS to dedicate a spot beam to a single MS under its jurisdiction by dynamically changing the antenna pattern as the MS moves; 4) in the forward link, each BS has a pilot channel to continuously broadcast its pilot signal to provide timing and phase information for all MSs in the cell. All the in-phase and quadrature components of the pilot signals are modulated with the same pair of pseudorandom noise (PN) codes, and each BS can be identified by its unique phase offset of the PN code sequences [12]. Each MS keeps monitoring the pilot signal levels from nearby BSs, and reports to the network those which cross a given set of thresholds (for soft hansoffs); and 5) both the forward-link and reverse-link transmissions are power controlled, except the forward-link pilot signals. As the system model is based on the IMT/UMTS proposals for the 3G systems, it does not impose much (if any) of extra implementation complexity for the mobile location.

5.3 TDOA/AOA LOCATION SCHEME

A. *Measurements for Mobile Location*

Consider 2-D MS location. It is assumed that, at any time, the MS to be located can receive forward-link pilot signals from its home BS and at least one neighbouring BS. Upon receiving the location service request, two types of measurements are carried out for the location purpose: 1) TDOA measurements at the MS receiver—As all BSs are time synchronized, the MS receiver can measure the time arrival difference between the pilot signals of a nonhome BS and the home BS by a PN code tracking loop which cross correlates the pilot signal from the nonhome BS with the pilot signal from the home BS. The pilot signal from each of the neighbouring BSs can be used in the MS location, provided the signal-to-noise ratio (SNR) of the received signal at the MS from the BS is above a certain threshold. The TDOA measurements can be obtained with an accuracy better than half chip duration if wireless propagation channel impairments are not severe [13]. The high chip rate in the 3G systems enables high accuracy TDOA measurements. The effect of interference and noise on the TDOA measurement accuracy can be reduced by increasing the integration time of the tracking loop. On the other hand, the Doppler shift puts a limit on the integration time, and other channel impairments such as fading and delay spread from the nonhome BSs can increase the TDOA measurement errors and 2) AOA measurements at the home BS—With an adaptive antenna array, the home BS steers its antenna spot beam to track the dedicated reverse-link pilot signal from the MS for improved reception. This provides the arriving azimuth angle of the signal from the MS. The forward-link

TDOA measurements will be forwarded to the home BS via the wireless channel, where both the forward-link TDOA and reverse-link AOA measurements are combined to give a location estimate of the MS, as described in Section IV.

B. AOA Modeling for Macrocell

The AOA measurement accuracy is critical to the location accuracy of the proposed scheme, and is dependent on the wireless propagation environment. A wireless channel contains objects (referred to as scatterers) which randomly scatter the energy of the transmitted signal. The scattered signals arrive at the receiver from various directions [14]. In a macrocell environment, the scatterers surrounding the MS are about the same height as or are higher than the MS. This results in the MS received signal arriving from all directions after bouncing from the surrounding scatterers. The AOA at the MS antenna can be modelled as a random variable uniformly distributed over $[0, 2\pi]$ [14]. On the other hand, the BS antennas are usually mounted at a level much higher than the surrounding scatterers. Hence, the received signal at the home BS mainly results from the scattering process in the vicinity of the mobile. The incoming waves from the mobile seen at the BS antenna are restricted to a small angular region [15], and the AOA is no longer uniformly distributed over $[0, 2\pi]$. For macrocell environments with relatively large BS antenna heights, a popular model for AOA at the home BS is that the effective scatterers are evenly spaced on a circular ring about the mobile [16], [17], as shown in Fig. 1, where θ_{BW} denotes the angle spread, R is the radius of the scatterer ring, D is the distance between the MS and the home BS, and β is the AOA of the reverse-link pilot signal. In general, θ_{BW} decreases as the BS antenna height increases. The circular model predicts a relatively high probability of multipath components within a small range of angles. Measurements reported in [18] suggest that AOA is Gaussian distributed and typical angle spreads are approximately two to six degrees for 1 km. Simulation results for outdoor multipath environments indicate that AOA can be measured with an accuracy better than four degrees [3]. For wideband radio channels, measurements (with a 10 MHz bandwidth centered at 1840 MHz) confirm that most of the received signal energy is concentrated in a small AOA region in rural, suburban, and even many urban environments [19]. In general, with wideband signaling, reflected signals are likely to arrive at the BS in a finite number of clusters, and the Gaussian wide sense stationary uncorrelated scattering (GWSSUS) model [20] is widely used to characterize this situation. An extension of GWSSUS to multiantenna AOA case is introduced in [21] and verified by field measurements. From the modeling and measurements, it is expected that, in a wideband macrocell environment, the home BS with a relatively large receiving antenna height is able to see a wave cluster containing the LOS component (called the LOS cluster) of the reverse-link pilot signal from the target MS. The LOS cluster is dominant in power and is mainly caused by local scatterers located close to the MS. Using the antenna array, the home BS is able to measure the AOA of the incoming pilot signal with an error within a few degrees.

5.4 Solution to TDOA/AOA Equations

In this section, a location estimator to solve the nonlinear TDOA/AOA equations for the MS location is derived. It is assumed that: 1) the TDOA and AOA measurement errors are independent Gaussian random variables with zero-mean and known variances and 2) there exists an LOS cluster in the AOA measurements.

A. Two BSs With Accurate Measurements

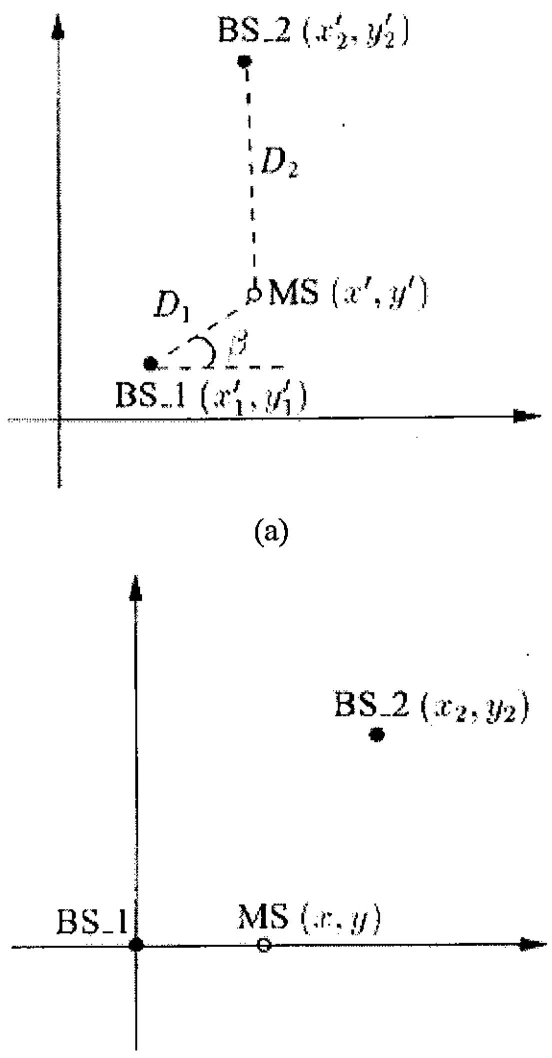
If the TDOA and AOA measurements are accurate, we need only the home BS and another BS to location an MS using the proposed location scheme. Consider the case as shown in

Fig. 2(a), where BS_1 is the home BS, BS_2 is the other BS, β is the measured AOA at 1 with respect to a reference direction (represented by the horizontal axis). From the AOA and TDOA measurements and the known location coordinates (x'_1, y'_1) and (x'_2, y'_2) of BS_1 and BS_2, respectively, the MS location (x', y') can be obtained by solving the following equations:

$$t_2 = \frac{1}{c}(D_2 - D_1), \quad \beta = \tan^{-1}\left(\frac{y' - y'_1}{x' - x'_1}\right)$$

where $t_2$is the TDOA between the pilot signals from BS_2 and BS_1,

$D_k = \sqrt{(y'_k - y')^2 + (x'_k - x')^2}\ (k = 1, 2)$is the distance between the MS and , and is the speed of light. The closed form solution to (1) is quite complex. For simplicity of analysis,



(a)

(b)

Fig. 5.1 : Location with two BSs and accurate measurements. (a) Original coordinates. (b) New coordinates.

a new coordinate system as illustrated in Fig. 2(b), which is obtained by rotating the axes of the old coordinate system clockwise by the angle β and by defining the BS_1 location as the origin. In the new coordinate system, the MS location is denoted by (x, y), BS_2 location by (x_2, y_2). Equation corresponds to

$$c \cdot t_2 = \sqrt{(x - x_2)^2 + (y - y_2)^2} - \sqrt{x^2 + y^2}, \quad y = 0$$

and the solution is

$$x = \frac{x_2^2 + y_2^2 - c^2 t_2^2}{2(x_2 + c t_2)}, \quad y = 0.$$

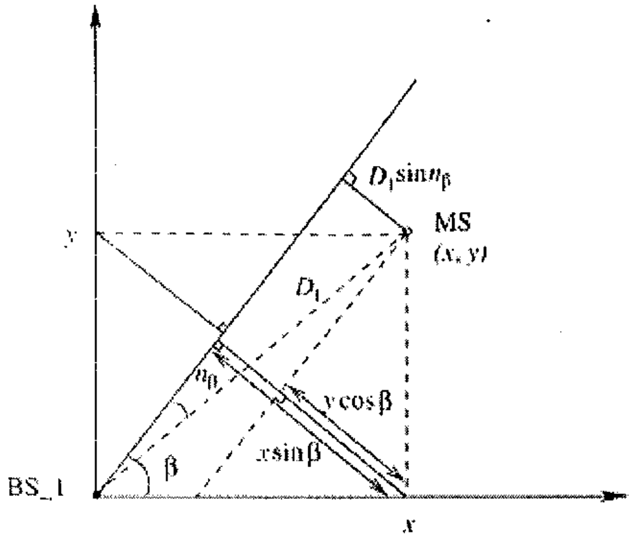


Fig. 5.2 : Linear approximation of the AOA equation

Note that (x_2, y_2) is in fact a function of the measured AOA, β, given by

$$x_2 = \sqrt{(x'_2 - x'_1)^2 + (y'_2 - y'_1)^2}\cos\left(\arctan\frac{y'_2 - y'_1}{x'_2 - x'_1} - \beta\right)$$
$$y_2 = \sqrt{(x'_2 - x'_1)^2 + (y'_2 - y'_1)^2}\sin\left(\arctan\frac{y'_2 - y'_1}{x'_2 - x'_1} - \beta\right)$$

In reality, due to propagation channel impairments, the TDOA and AOA measurements contain errors. As a result, there may not exist a solution to (1), i.e., the measurements involving only two BSs may not lead to an MS location estimate. More than two BSs are usually required for a location estimate of reasonable accuracy.

B.(K≥3) BSs With 2-D Array Layout

When there are (K≥3) BSs available for the MS location, a set of overdetermined nonlinear location equations is obtained. The equations incorporating the measurement errors are given by

$$t_k = \frac{1}{c}(D_k - D_1) - n_k, \quad \beta = \tan^{-1}\left(\frac{y - y_1}{x - x_1}\right) + n_\beta$$

where k= 2 , ..., K ,n_k is the TDOA measurement error associated with BS_k and η_β the home BS, and is the measurement error of the AOA. In the following, the LS solution to this problem is discussed, which is an ML estimator when the measurement errors are small.

1) *Taylor-Series Linearization:* Consider the AOA equation in (5). Using the home BS as the coordinate origin, the following geometrical relationship is obtained, as shown in Figure.

$$D_1 \sin n_\beta = x \sin \beta - y \cos \beta.$$

Using the fact that $\sin \eta_\beta = \eta_\beta$ when $\eta_\beta << 1$, we can approximately rewrite the AOA equation in a linear form as

$$0 \approx -x \sin \beta + y \cos \beta + D_1 n_\beta$$

As a result, the above equation can be rewritten in a matrix form as

$$\boldsymbol{m} = \boldsymbol{f}(\boldsymbol{\theta}) + \boldsymbol{n}.$$

where

$$\boldsymbol{\theta} = \begin{bmatrix} x \\ y \end{bmatrix}, \quad \boldsymbol{m} = \begin{bmatrix} t_{2,1} \\ t_{3,1} \\ \vdots \\ t_{K,1} \\ 0 \end{bmatrix}$$

$$\boldsymbol{f}(\boldsymbol{\theta}) = \begin{bmatrix} (D_2 - D_1)/c \\ (D_3 - D_1)/c \\ \vdots \\ (D_K - D_1)/c \\ -x \sin \beta / D_1 + y \cos \beta / D_1 \end{bmatrix}$$

and

$$\boldsymbol{n} = \begin{bmatrix} n_{2,1} \\ n_{3,1} \\ \vdots \\ n_{K,1} \\ n_\beta \end{bmatrix}.$$

The measurement error $\boldsymbol{n}$ is assumed to be a multivariate random vector with zero mean and a $K \times K$ positive definite covariance matrix given by

$$\boldsymbol{Q} = \begin{bmatrix} \boldsymbol{Q}_t & 0 \\ 0 & \sigma_\beta^2 \end{bmatrix}$$

where Q_t is the covariance matrix for TDOA measurement errors, and σ^2_β is the variance of the AOA measurement error. Equation (8) can be solved by the Taylor series expansion
method [6].

2) *Two-Step LS Approach:* The linearized LS estimator using Taylor series expansion is an ML estimator and can achieve high accuracy, provided the linearization error is small and the initial guess of the MS location is accurate enough. The estimator is computationally intensive and has a convergence problem [2]. To solve this problem, the two-step LS approach for TDOA equations [6] to the hybrid TDOA/AOA location is extended, which requires the AOA equation to be a linear function of x, y , and D_1. Equation (7) is the required format. Let $\boldsymbol{\theta}_a = [x,y,D_1]^T$ be the unknown vector. Let superscript 0 denote the error-free value of a variable. The matrix form of the TDOA/AOA equations in the presence of the measurement error **n** is

$$\boldsymbol{m}_a = \boldsymbol{G}_a \boldsymbol{\theta}_a^0 + \boldsymbol{\psi}_a$$

where

$$\boldsymbol{m}_a = \frac{1}{2}\begin{bmatrix} D_{2,1}^2 - L_2 \\ D_{3,1}^2 - L_3 \\ \cdots \\ D_{K,1}^2 - L_K \\ 0 \end{bmatrix}$$

$$\boldsymbol{G}_a = -\begin{bmatrix} x_2 & y_2 & D_{2,1} \\ x_3 & y_3 & D_{3,1} \\ & \cdots & \\ x_K & y_K & D_{K,1} \\ -\sin\beta & \cos\beta & 0 \end{bmatrix}$$

$$\boldsymbol{\psi}_a = c\boldsymbol{B}\boldsymbol{n} + \frac{c^2}{2}\boldsymbol{n} \odot \boldsymbol{n} \begin{bmatrix} \boldsymbol{I}_{K-1} & 0 \\ 0 & 0 \end{bmatrix}$$

$$\boldsymbol{B} = \mathrm{diag}\{D_2^0, \ldots, D_K^0, D_1^0/c\}$$

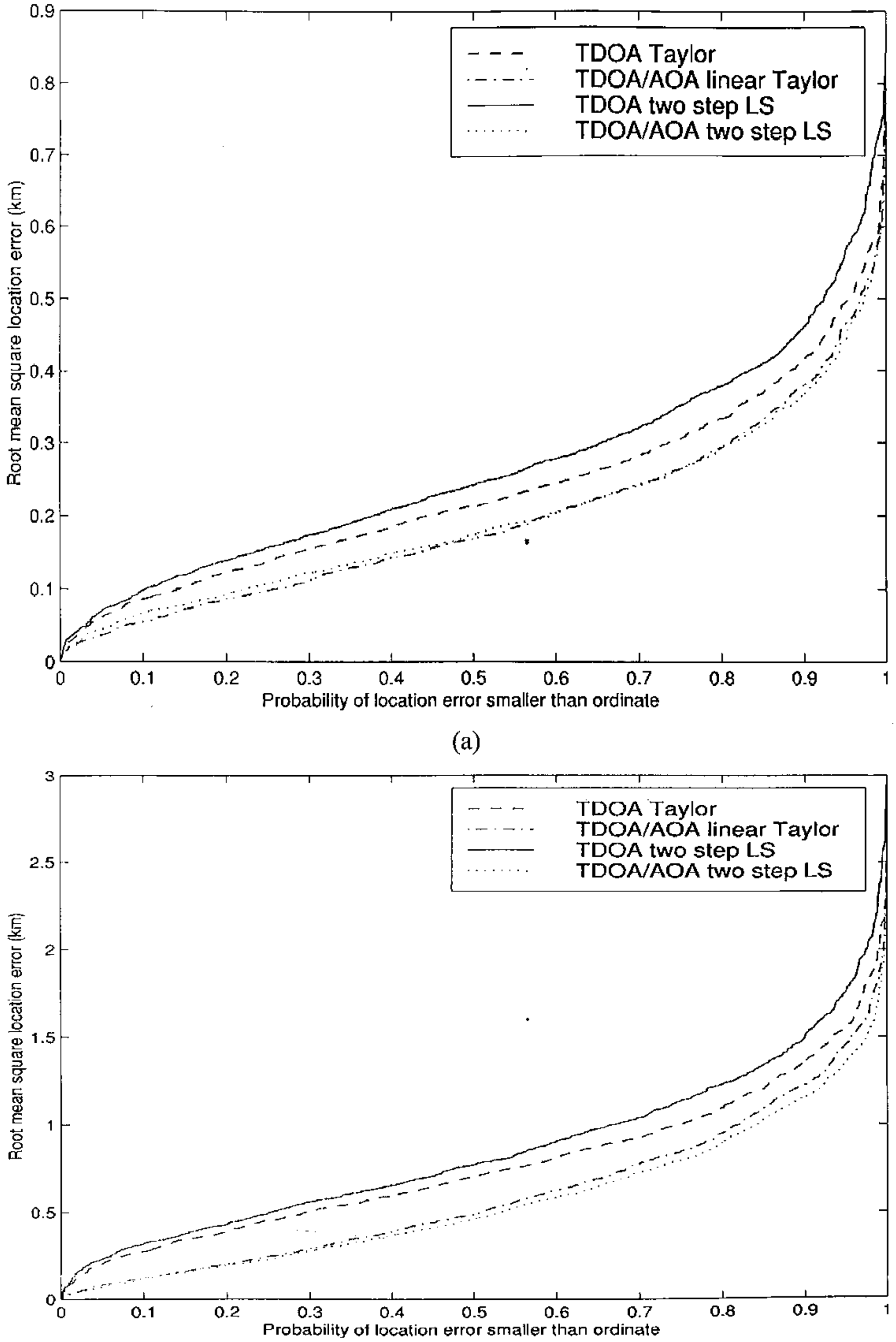
I_{K-1} is the K-1 × K-1 identity matrix, and □ represents the Schur product (element-by-element product).An approach similar to that given in [6] to solve the LS estimation problem can be used.

5.5 Simulation Results

Computer simulations are performed to demonstrate the performance of the proposed location scheme.It is assumed that the TDOA and AOA measurement errors are independent Gaussian random variables with zero-mean and that variances of the TDOA measurement errors associated with different BSs are identical unless otherwise specified. For the 2-D location, a hexagonal test cell surrounded by 6 neighbouring cells with radius of 5 km is considered. The RMS error is computed based on 10 000 independent runs. The initial position guess in the Taylor-series method is chosen to be the true solution to allow for convergence. Simulations show that at least three iterations are required for Taylor-series solutions to convergence. In the simulations, the variances of the measurement errors are given. In practice, the variances depend on the chip rate, the propagation environment, and the home BS antenna parameters. They can be estimated based on the received signal SNRs and their typical values for various propagation conditions.

The Effect of TDOA and AOA Measurement Accuracy

Fig. 5.3 shows the location accuracy of the proposed TDOA/AOA location as compared with that of the TDOA only location, with 0.1 and 0.316 km, respectively, and 1 degree. The MS is located at the coordinates (3, 3) km. It is observed that: 1) the TDOA/AOA location always performs better than TDOA only location for both the Taylor series estimator and the two-step LS estimator; 2) for TDOA only location, the Taylor series estimator generally gives slightly better performance than the two-step LS estimator, provided it converges. However, for the hybrid TDOA/AOA location, the performance of the two-step LS estimator is very close to that of the Taylor series estimator; and 3) with larger TDOA measurement errors, the performance improvement introduced by additional AOA is more significant.



(a)

(b)

Figure 5.3: Performance comparison between the TDOA/AOA location and TDOA only location, four BSs, true MS location at (3, 3) km.(a) $c\sigma_t$ =0.1 km, σ_β = 1° . (b) $c\sigma_t$ = 0.316 km, σ_β = 1°.

5.6 Summary

The third-generation (3G) wireless systems are currently under development in some parts of the world and have been deployed in others. The current Radio Transmission Technology proposals for 3G wireless mobile systems employ wideband code-division multiple-access (CDMA) technology. The systems will offer a wide range of multimedia communication services and user location service. The Taylor-series approach can achieve high accuracy, but requires an initial location guess and may suffer from the convergence problem if the initial guess is not accurate enough. Furthermore, it is an iterative approach and is computationally intensive as it needs to determine the local linear least-square (LS) solution in each iteration.

To overcome the drawbacks, a two-step LS estimator for the TDOA location was proposed. For understanding of the CDMA system the the wideband CDMA system model was discussed. AOA modelling for macrocell was studied under TDOA/AOA location scheme measurements for mobile Location. Solution to the TDOA/AOA technique was discussed considering two BSs with accurate measurements and 3 and more than 3 BSs. Two approaches were mentioned; 1) Taylor-Series Linearization, and 2) Two-Step LS Approach

Simulation results were given.

CHAPTER 6

Results and Conclusions

6.1 Conclusion

Methods and Algorithms for TDOA Position Location

The hyperbolic position location method which is also called the Time-Difference-Of-Arrival (TDOA) method finds out the position estimation in two steps. In the first step we estimate the time difference of arrival of the signal between at least two pairs of base stations and in the second step we solve the hyperbolic equations obtained as a result of those TDOA measurements. For the estimation of TDOA, the method most commonly used is cross-correlation of received signals at any pair of base stations. There exist a lot of methods and algorithms to improve the estimation accuracy of the cross-correlation method. They can be broadly classified into two categories. Generalized Cross-Correlation (GCC) methods try pre-filtering the signals before cross-correlation to suppress the portions of spectrum that have a concentration of noise and interference and to enhance the spectral parts where SNR is higher. Among the methods available for solving the non-linear hyperbolic equations, formed from the TDOA estimates, it is found that the most suitable are Taylor-Series Method, Fang's Method and the Chan's Method. Chan's method is the most suitable as it offers a closed form and exact solution and can take advantage of redundant measurements, if available, to further reduce the position location error.

Effect of AWGN

To study the effects of AWGN level on the position location accuracy, simulations were performed at different noise levels. In these results, three base stations were used. Fifteen users were assumed to be active in each cell. A sampling rate of 8 samples per chip was used. Frequency of operation was 900 MHz. The snap shot for cross-correlations had a length of 12 bits which is equal to 1536 chips in IS-95. The bandwidth and chip rate also corresponded with that of IS-95. The TDOA estimation noise was kept at a standard deviation of 10 ns. The calculations were made at eight different values of E_b/N_0 from 1 dB to 15 dB. This range is around the typical values of operation for a CDMA system. At each value of E_b/N_0, position fixes were obtained while placing the mobile randomly at different locations within the cell. From the measurements, the PL error was calculated using the known original position of the mobile. To average out the difference in performance at different positions within the cell, 1000 random measurements were taken for each value of E_b/N_0. The results are presented in Figure 6.1.

The graph shows that the accuracy improves as the E_b/N_0 increases. The performance reaches the FCC requirement, once the E_b/N_0 goes above approximately 9 dB. This simulation does not include channel coding and hence the coding gain has not been accounted for. Hence, it is expected that the performance should be better in real systems and the requirement may be met at lower levels of E_b/N_0.Tthe improvement is much sharp at lower levels of E_b/N_0 and then becomes slower at higher values. The reason is that when the AWGN levels become insignificant the system performance becomes dependent only on the interference from other users. Since number of interferers for the 911 user is kept constant, hence, after a certain level the improvement in E_b/N_0 does not provide much gain in position location accuracy. Based on the results of this simulation, the E_b/N_0 in many other simulations has been maintained at 10 dB.

Fig. 6.2 shows the performance comparison for the MS located at (0.4, 0.4) km. When the MS is close to the home BS, the Taylor series method has convergence problem if the initial guess is not accurate enough. It is observed that the TDOA/AOA two-step LS estimator gives best performance, followed by the TDOA/AOA Taylor series estimator. Additional AOA information is very useful here to reduce the otherwise large location estimation error. Fig. 6.3 shows the comparison when the variance of the TDOA measurement error associated with 2 is ten times of that associated with 3 and 4. The TDOA/AOA location using both the Taylor series estimator and the two-step LS estimator gives an RMS error almost 0.2 km smaller than that of the corresponding TDOA only location. The TDOA/AOA two-step LS estimator performs slightly better than the TDOA/AOA Taylor series estimator. In the case that some of the BSs have a larger TDOA measurement error variance than others, the AOA

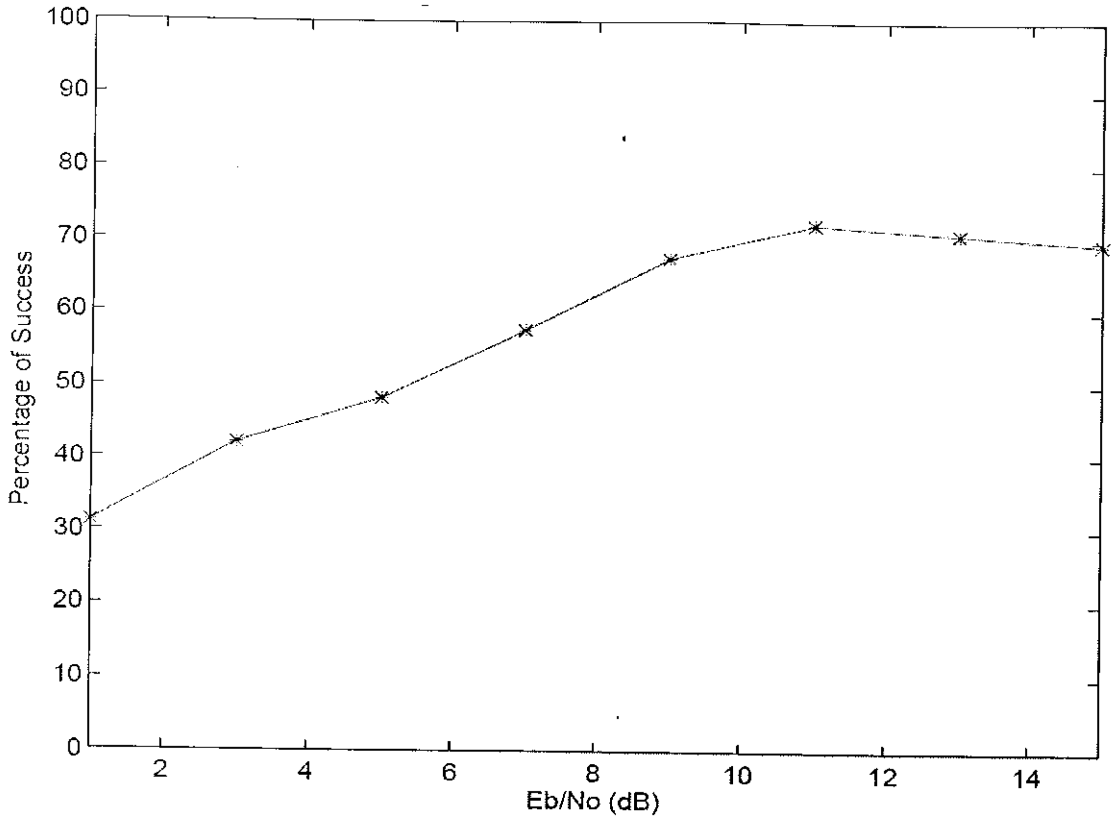


Figure 6.1: Position Location Performance at Different AWGN Levels (Sampling Rate = 8 samples per chip, Snap Shot Length = 12 bits, σ_d = 10 ns, 15 users per cell)

information greatly reduces the RMS location error. Table I gives the RMS errors and the CRLB of the location methods with various numbers of the BSs. It is observed that, for all the numbers of the BSs, the proposed TDOA/AOA location outperforms TDOA only location. Fig. 6.3 shows the location accuracy comparison versus. It is observed that: 1) a large performance improvement by the TDOA/AOA location is achieved when the AOA measurement is accurate and 2) the TDOA/AOA location always performs better than the TDOA only location. However, when the AOA measurement error increases to a certain level, the performance improvement becomes negligible.

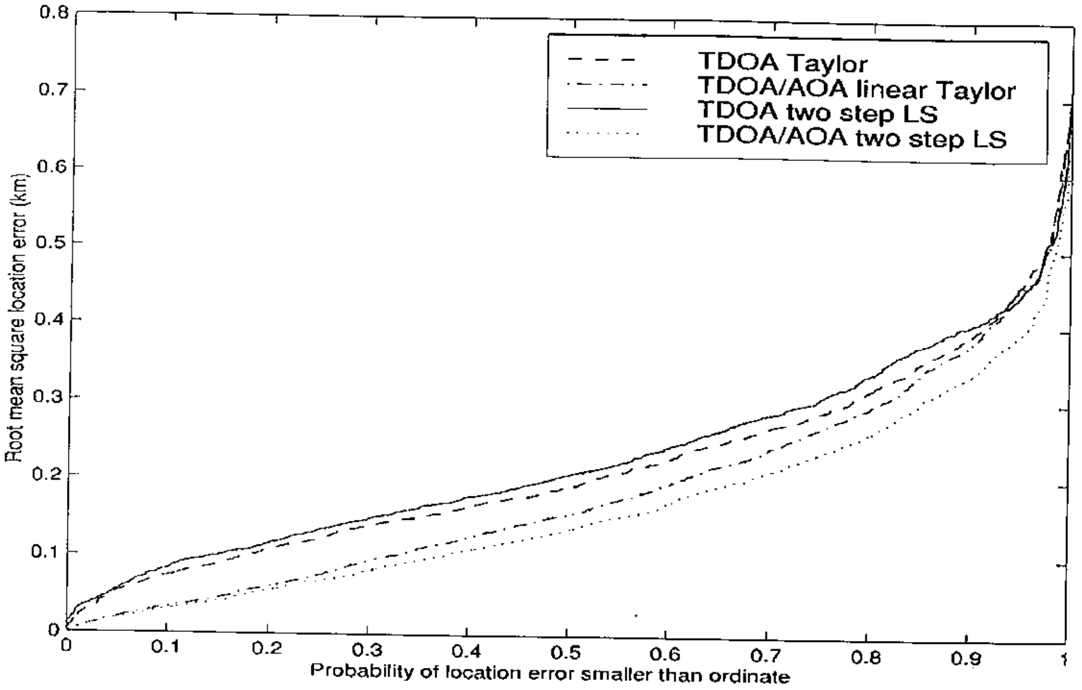


Figure 6.2 : Performance comparison between the TDOA/AOA location and only location, $c\sigma_t = 0.1$ km, $\sigma_\beta = 1°$, four BSs, true MS location at (0.4, 0.4) km.

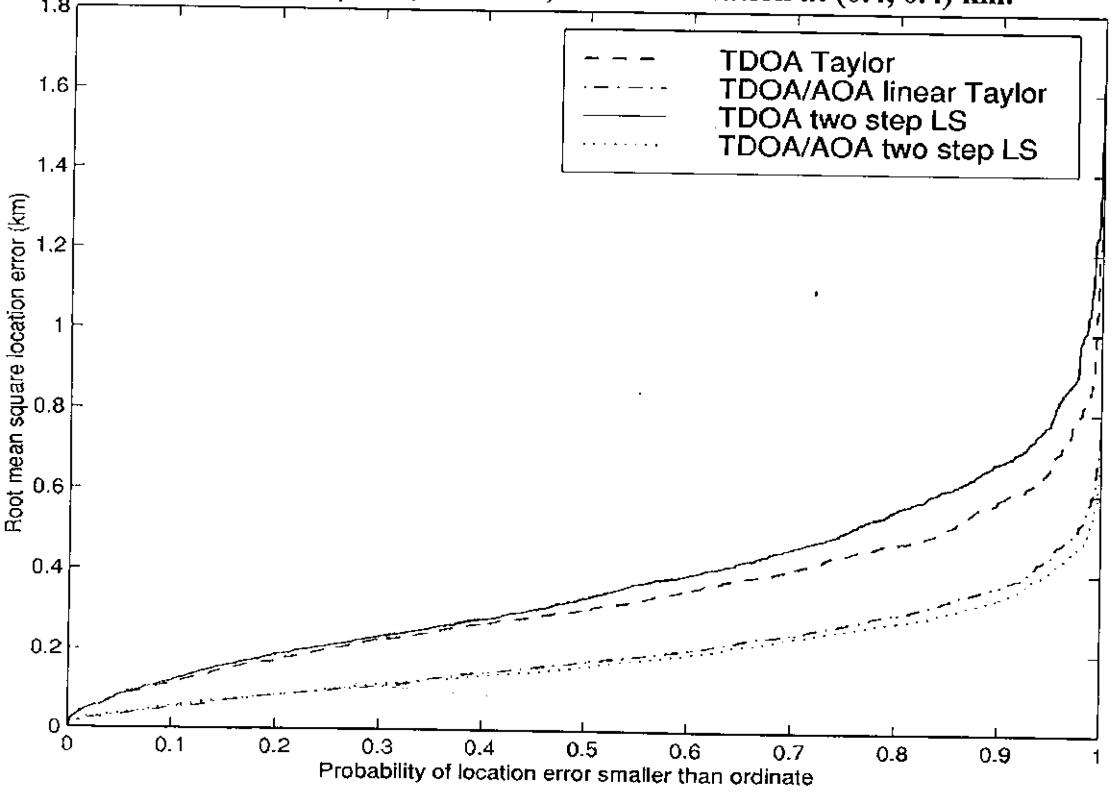


Fig. 6.3 : Performance comparison between the TDOA/AOA location and TDOA only location, $c\sigma_t = 0.1$ km, $\sigma_\beta = 1°$; $c\sigma_t = 0.316$ km, four BSs, true location (3, 3) km.

6.2 Future Work

The work done in this research can be extended in some ways. Apart from the study of these methods, research can also be directed towards some related technical issues. There may be some situations when only one base station is able to receive the signal from the 911 mobile. Such a situation may occur in rural or suburban areas where extensive coverage is not needed.

Another area of research may be to study the inaccuracies resulting from the total absence of a LOS component in the 911 user's signal. The study of this type of situation is important because there can be such cases in real environments where there is no LOS component at all as this can lead to errors in TDOA estimation.

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